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REAL-TIME GRID RELIABILITY MANAGEMENT

California ISO Real-Time Voltage Security Assessment (VSA) Prototype Functional Specifications/Prototype Development

APPENDIX C

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Research and develop a voltage security assessment (VSA) prototype to monitor system voltage conditions and provide real time dispatchers with reliability information related to reactive margin, abnormal nodal voltages, weak elements and contingency rankings.

1.2 Technical Survey

The California ISO, the California Energy Commission (Energy Commission) and the Consortium for Electric Reliability Technology Solutions (CERTS) initially agreed to develop a real-time voltage and transient analysis security margin assessment tool using hyperplane technology. The California ISO had proposed using the concept of hyperplane to implement this objective. A survey was conducted among experts to determine the feasibility of implementing this approach. The experts agreed that the hyperplane approach is well suited for voltage assessments but not yet proven to conduct transient analysis. Upon completion of the survey, the Energy Commission, California ISO and CERTS agreed to implement a hyperplane-based voltage security assessment (VSA) prototype for the California ISO control area. No transient analysis will be performed with hyperplanes at this time.

1.3 VSA Project Summary

Objective

Develop a prototype for real-time voltage security assessment (VSA) application and prepare functional specifications to be used by California ISO to select a vendor and for vendor to use it in the development of a production quality application for California ISO.

Real-Time Voltage Security Assessment Project: Research and develop a voltage security assessment (VSA) prototype to monitor system voltage conditions and provide system operators with real-time reliability metrics related to reactive margin, abnormal nodal voltages, weak elements, and contingency rankings.

What Will The Application Do?

The VSA application will take California ISO system model and data, develop security regions (a form of nomogram) using hyperplanes, calculate security indices, and identify and display abnormally low voltages and weak elements. This application will also perform contingency analysis and provide the system operators with contingency rankings for system monitoring and correction.

Why Is the Application Needed?

The California ISO and neighboring systems are experiencing an increase in reactive power consumption. Inadequate reactive supply was identified as a cause of the

August 2003 blackout, and closer management of voltage is a key objective for reliability. This application will allow the system operators and reliability coordinators to monitor system voltage conditions and detect conditions that make the system vulnerable to voltage collapse and to take timely preventive actions. It will also provide operating staff with a more realistic security assessment with the potential of better utilization of the system facilities.

How Will the Application Benefit the Operators and Reliability Coordinators?

This application will provide near real-time assessment of voltage conditions and how they relate to safe and secure operating limits under normal and contingency conditions. System operators and reliability coordinators can use this information to evaluate and implement corrective actions such as generation rescheduling, reactive VAR switching, and/or load shedding.

What Are the Requirements to Implement This Application?

The VSA application will use data from the California ISO state estimator and, therefore, will need to be connected to California ISO system such that there is a continuous flow of model and data for analysis by the VSA application. The California ISO suggested the Humbolt area be used in the development of the prototype. California ISO will assist CERTS/EPG with the following:

- Initially provide a GE California ISO system solved case with emphasis on the Humbolt area. Later, provide a solved case from the California ISO State Estimator in PSLF bus/branch format.
- An algorithm to stress the system feeding the Humbolt area.
- A contingency file selecting relevant contingencies to be analyzed in the prototype development.

1.4 Project Grid Monitoring Visualization Solution

The VSA application will be designed for use by the California ISO operators in monitoring and predicting system performance two hours ahead. CERTS-EPG will work with the CA ISO to design a data display format suitable to California ISO operators. The real time display will have the following information:

- Security region whose security boundaries are determined in MW flows.
- The current operating condition.
- Worst case contingencies leading to voltage collapse.
- Contingencies with insufficient stability margin.
- Contingency ranks based on severity indices.
- Abnormal reductions of nodal voltages.
- Voltage security margins.
- Weak elements and geographical locations.

The real-time security display will use a four-panel display format developed by CERTS/EPG. This display will be designed taken into account the results of a yet to be performed Human Factor analysis.

2.0 BACKGROUND

2.1 Key Definitions

Security Region – The set of operating conditions where it's safe for the power system to operate. This region will be bounded by hyperplanes developed offline.

Hyperplane – A boundary established through offline analysis determined by stressing a cut set until the system reaches a state of voltage system instability.

Voltage Stability – The ability of a power system to maintain adequate voltages at all buses in the system under varying loading conditions.

Voltage Collapse – The condition where there is uncontrollable decay in system voltages at one or more load buses or even a significant portion of the network.

Security Margin – The available margin on a transmission path determined by subtracting the MW (or MVAR) flow on a transmission path from the MW (or MVAR) limit determined by the corresponding hyperplane.

Weak Element – Defined as the power system location where voltage collapse has occurred upon directional stressing on a transmission path.

2.2 Voltage Security Assessment

The California ISO, the California Energy Commission (Energy Commission) and the Consortium for Electric Reliability Technology Solutions (CERTS) initially agreed to develop a real-time voltage and transient analysis security margin assessment tool using hyperplane technology. Hyperplane technology consists in running a series of power flows with a specialized convergence technique to identify operating points in the system where a voltage limit has been reached.

The California ISO had proposed using the concept of hyperplane to implement the objective outlined above. A survey was conducted among experts to determine the feasibility of implementing this approach. The experts agreed that the hyperplane approach is well suited for voltage assessments but not yet proven to conduct transient analysis. Upon completion of the survey, the Energy Commission, California ISO and CERTS agreed to implement a hyperplane-based voltage security assessment (VSA) prototype for the California ISO control area. No transient analysis will be performed with hyperplanes.

3.0 VOLTAGE SECURITY ASSESSMENT FUNCTIONALITY

The VSA will produce security regions periodically and perform voltage assessment every five minutes for the current system condition and for the next two hours in five-minute increments. The VSA prototype will develop security regions and, using a post processing algorithm, perform an analysis of a given system conditions that will include the following functionality:

- Contingency simulation
- Determination of voltage security margins
- Contingency ranking
- Identification of weak elements

3.1 Contingency Simulation

The prototype will have the ability to take a base case provided by the California ISO, convert it to a format usable by the prototype, and run power flows until an acceptable solution is reached for the condition at hand. The prototype will also have the capability to take system elements such as predefined transmission lines, generators, and transformers out of service and run power flows without those elements.

The ultimate version of the VSA application shall have the ability to develop security regions and perform voltage security assessment on demand, for system conditions when a contingency has already occurred. The application shall also be able to, using the modified topology, perform contingency analysis in anticipation of the next contingency.

3.2 Voltage Security Regions and Hyperplanes

The prototype will define the voltage security regions whose boundaries are piece-wise linear approximation (hyperplanes) in coordinates of nodal power injections and power flows. To determine the hyperplane nomograms or security regions, the prototype shall perform a series of continuation power flows until the point of voltage collapse is reached; this point of voltage collapse will determine the hyperplane for the direction being stressed. Other limits reached during this stressing process such as thermal and voltage violations will be identified and reported. The user will specify a transfer or loading by either a vector indicating the participation of all the load and generator buses, or some other pattern that represents actual system loading conditions. The user will also specify the structural changes and/or system performance limits to be used during power flow runs.

3.3 Voltage Security Margin Assessment

For the operating condition in question, the voltage security margins are determined from the voltage security regions developed offline for normal and contingency conditions. The distance from the current operating condition to the relevant edge of the security region will determine the voltage security margin for the condition at hand.

3.4 Contingency Rankings

Contingency ranking will be determined by an algorithm that will sort the results of contingency analysis by either voltage security margin or by abnormal reduction of nodal voltages. Ranks will be specified with 1 as the contingency resulting in the smallest security margin or worst nodal voltage deviation.

3.5 Identification of Weak Elements

Weak elements, defined as those lines and or substations which are most affected by those contingencies causing worst damage to the reliability of the power system, will be determined by an algorithm based either on analysis of the direction of the critical vector or on analysis of the practical stability criteria (derivatives or sensitivities of active and reactive power with respect to variations of nodal voltage). CERTS/EPG and California ISO will jointly decide on the most appropriate method. In addition the VSA application will produce scale-independent ranking using ratios for the most sensitive buses in the system.

CERTS/EPG and the California ISO agreed to test this functionality focusing on the Humbolt area, where voltage problems are known to exist.

4.0 DATA REQUIREMENTS

The VSA tool will rely on state estimator data and will initially be used as an off-line application. Later, this tool can be expanded for real-time use. When used as an off-line application, the prototype will require data from the California ISO's state estimator including the following:

- California ISO control area model
- California ISO control area solved power flows with state estimator data including MW and MVARS for load, generators and interchanges. These power flows should include heavy load conditions and heavily loaded transfer paths.
- Generator limits, voltage thresholds, and line ratings.

In addition, the Voltage Security Assessment application will need the following information to determine hyperplanes and develop security regions:

- Transmission path loading vectors and any other system loading patterns relevant to the power system condition under review.
- Load and generation forecasts for two consecutive hours in intervals of five minutes.
- A list of relevant single outage contingencies and double element outages selected based on California ISO's operational experience

When used as a real time application the tool will need direct input from the California ISO state estimator to receive California ISO control area real-time data together with control area model, generator and thresholds limits and transmission path loading vectors.

CERTS/EPG and the California ISO agreed to develop the VSA prototype using a continuation power flow engine provided by the Power System Engineering

Research Center (PSERC). This application uses a bus/branch configuration, and the input for this engine will be generated from a GE solved case to be provided by the California ISO's planning group. When the California ISO State estimator produces PSLF formatted cases, the prototype will be tested using these cases.

Additional data requirements will be identified once algorithms are selected and the corresponding design specifications are developed.

5.0 VISUALIZATION SOLUTION APPROACH AND ARCHITECTURE

The VSA real-time display will use a visualization solution based in a multi-view, geographic, approach that will include the following information:

- Security region whose security boundaries are determined in MW flows.
- The current operating condition.
- The voltage security margin available with the system condition at hand.
- Abnormal reduction of nodal voltages.
- Contingency ranks based on severity indices.
- Weak elements and geographical locations.
- Worst case contingencies leading to voltage collapse.
- Contingencies with insufficient stability margin.

6.0 SYSTEM ARCHITECTURE

The voltage security assessment prototype will be based on a power flow computational engine equipped to handle a continuation method algorithm necessary to solve numerous power flows quickly. Computational speed is necessary to solve many power flows in a short period of time to develop security regions based on piece-wise linear approximation (hyperplanes) of stability boundaries.

The VSA prototype system architectural overview is shown in Figure 1. Each of the different components of the application is described below:

Case Reader/Network Processor
The case reader component will be designed to interface with the state estimator California ISO data source and to read a complete base case and translate into a format suitable for use with the VSA computational engine. It will also have the ability to read the contingencies files and modify the system topology to simulate outages.

Transfer Path/Loading Direction Selector
This application will select the path to be stressed and use the load and generation pattern provided by the California ISO to in the directional stressing algorithm. This application will keep track of paths (cut sets) selected for directional transfer increases (path stressing). A new path will be selected for stressing only after the current path has been stressed to a point of voltage

collapse and a hyperplane has been identified for that path.

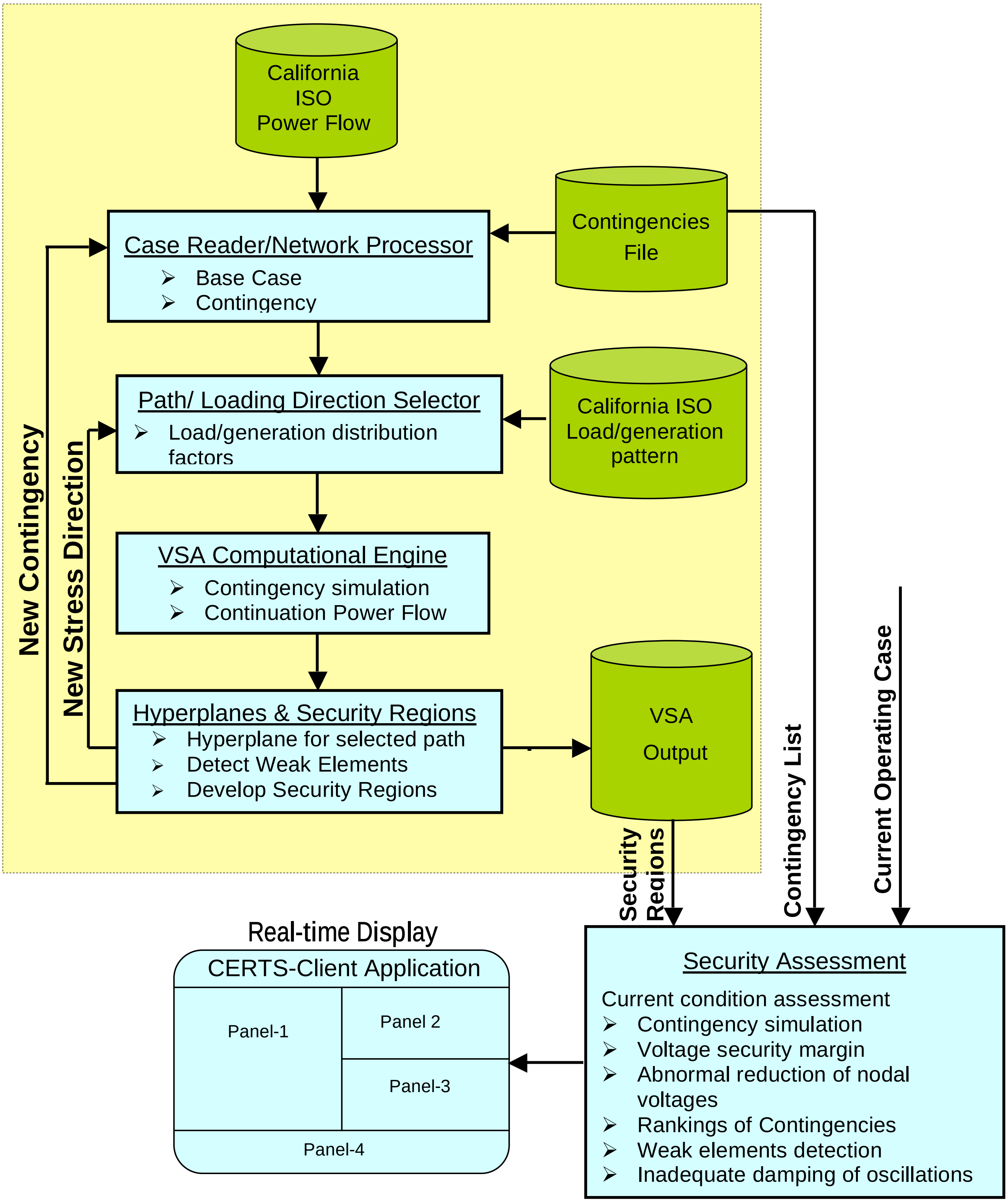

Figure 1: Voltage Security Assessment Prototype (System Architecture)

Source: CERTS

VSA Computational Engine
At the center of the application is the VSA computational engine designed to take base case models and corresponding data from the California ISO state estimator, run power flows, and determine the distance to voltage collapse. Abnormal reduction in nodal voltages will be identified during these runs.

Hyperplane and Security Regions
At the voltage collapse point for a particular stressing direction, this function will use a linearization process to calculate the hyperplane and identify the weak elements. The set of hyperplanes developed for different transfer paths constitute the boundaries of the safe, stable, region and therefore define a security region. These security regions shall be defined for each contingency condition in a pre-determined contingency file. This file will be either provided by the California ISO or will proceed from a contingency screening application.

Security Assessment
For the operating point in question, this component will perform the following:

- Analyze the current system conditions and map it to the security region.
- Access and display the security regions developed for the different system conditions including contingencies.
- Calculate the voltage security margin for the current system condition.
- Identify abnormal reduction of nodal voltages.
- Rank contingencies based on the security indexes obtained from contingency analysis.
- Identify the weak elements.

Client Application
The CERTS client application will read all the results obtained with the voltage security assessment applications and display the following information for use by the dispatchers:

- Security region whose security boundaries are determined in MW flows.
- The current operating condition.
- Worst case contingencies leading to voltage collapse.
- Contingencies with insufficient stability margin.
- Contingency ranks based on severity indexes.
- Abnormal reductions of nodal voltages.
- Voltage security margins.
- Weak elements and geographical locations.

7.0 IMPLEMENTATION SCHEDULE

Table I: Implementation Schedule for the California ISO Voltage Security Assessment Project

ACTION	Completion	
	Target	**Done**
PHASE 1		
Complete contingency analysis and ranking	3/30/2005	√
Factory test completed	4/15/2005	√
PHASE 2		
Project Executive Summary	2/18/2005	√
Assess and research algorithms (Survey) to determine security regions; prepare summary of responses	3/15/2005	√
Define algorithm to determine security regions for CA ISO	3/25/2005	√
Functional Specifications	3/30/2005	√
Complete Survey report for delivery	4/15/2005	√
Customer Approval of Functional Specs	4/15/2005	√
Design Specifications	5/20/2005	
Prototype Development:		
● Complete Case Reader/Network Processor	6/3/2005	
● Complete Path/Loading Direction Selector	6/3/2005	
● Complete VSA Computational Engine	6/10/2005	
● Complete hyperplane identifier	7/1/2005	
● Complete security assessment application	7/29/2005	
Integration - VSA prototype	8/19/2005	
Validation using GE program	TBD	

Source: CERTS